

SURVEYING SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

5 The present invention relates to a surveying system. In particular, it relates to a surveying instrument or system, including a total station, an electronic tacheometer, or the like, that is able to measure an angle and a distance relating to a measurement
10 point.

2. Description of the Related Art

 Generally, a surveying operation requires at least two persons. Namely, one holds a target, such as a prism or the like, at a measurement point, while the
15 other person operates a surveying instrument. In the surveying operation, in order to obtain measurement data for a plurality of measurement points, the person with the target should move to each of the measurement points, and the other person should sight the surveying
20 instrument to the target, each time the target moves to a measurement point. Therefore, the conventional surveying operation is quite cumbersome and requires at least two people and a lot of time, so it is inefficient and expensive. Recently, a non-prism-type surveying
25 instrument, which requires no target, has been developed.

With the non-prism-type surveying instrument, the person who carries the target can be excluded and the surveying can be carried out by a single person who operates the surveying instrument, so that the efficiency of the surveying operation is improved. However, even when using the non-prism-type surveying instrument, the operator should still carry out sighting operations for each of the measurement points. This becomes extremely cumbersome and requires time particularly when the number of measurement points is large, such as when estimating the volume of a basin or hollow ground to be buried.

SUMMARY OF THE INVENTION

Therefore, an object of the present invention is to improve efficiency of the surveying operation. More particularly, the invention aims to cooperate measurement information obtained by a surveying instrument and image information of a surveying area which is obtained by a camera, simply and efficiently, thereby improving efficiency.

According to the present invention, a surveying system is provided. The system comprises a surveying device, a collinear-line calculating processor, a sighting direction control processor, and an object-point searching processor.

The collinear-line calculating processor obtains

a collinear line which provides a collinear condition for an arbitrarily designated point on a schematic image of which the positional relation to the surveying device is known. The sighting direction control processor controls
5 the sighting direction of the surveying device to move along the collinear line. The object-point searching processor searches for an object point that can be determined as a point on the collinear line by measuring the sighting direction with the surveying device, while
10 carrying out the sighting direction control procedure. Further, the position obtained by the object point searching processor coincides with an object point that corresponds to the designated point on the schematic image.

15 Further according to the present invention, an automatic surveying system is provided that comprises a position relation calculating processor, a correspondence establishing processor, an input device, and a sighting direction control processor.

20 The position relation calculating processor calculates a positional relation between a coordinate system to which measurement information of a measurement point refers and a schematic image of a surveying field, which includes the measurement point. The correspondence
25 establishing processor establishes correspondence between

measurement information of the measurement point and position information of a point corresponding to the measurement point on the schematic image with respect to the above positional relation. The input device enables
5 a designation of a measurement point on the schematic image. The sighting direction control processor controls a sighting direction of a surveying device in accordance with the position of the designated measurement point on the schematic image, which is designated by using the
10 input device.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects and advantages of the present invention will be better understood from the following description, with reference to the accompanying drawings
15 in which:

Fig. 1 is a block diagram showing a general electrical construction of a surveying system for an embodiment of the present invention;

Fig. 2 is a flowchart of the survey operation
20 processes in the surveying system;

Fig. 3 schematically illustrates an arrangement of the surveying instrument and the camera;

Fig. 4 schematically illustrates the relations between the control points and the corresponding image
25 points on the imaging surface S;

Fig. 5 is a flowchart of the space resection program that calculates exterior and inner orientation parameters;

Fig. 6 schematically illustrates an example of the schematic image indicated on the display;

Fig. 7 schematically illustrates the principle of an automatic surveying operation in the present embodiment;

Fig. 8 is a flowchart of the automatic surveying operation in the present embodiment;

Fig. 9 is a flowchart of an object point searching process which is carried out in Step S303 of Fig. 8;

Fig. 10 schematically illustrates the relation between the sighting telescope of the surveying instrument and the surveying coordinates;

Fig. 11 is a flowchart of the unit collinear vector calculating process;

Fig. 12 is a flowchart of the surveying operation for an alternate embodiment; and

Fig. 13 is a flowchart of the surveying operation for an alternate embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is described below with reference to the embodiments shown in the drawings.

Fig. 1 is a block diagram showing a general

electrical construction of an embodiment of the present invention, which includes a surveying instrument and a camera.

A surveying instrument 10 of the present
5 embodiment may be a total station or the like that comprises a sighting telescope 17. The sighting telescope 17 has a horizontal axis L_h for measuring an altitude θ_p , and a vertical axis L_p for measuring a horizontal angle θ_h . Namely, the sighting telescope 17 is
10 vertically rotatable about the horizontal axis L_h and horizontally rotatable about the vertical axis L_p . The horizontal axis L_h and the vertical axis L_p intersect at point O_s (referred to as the sighting origin O_s in the following) at a right angle. The optical axis LN_o (or
15 collimation axis) of the sighting telescope 17 passes through the sighting origin O_s . The optical axis LN_o is bifurcated by a half-mirror 18, so that one of the bifurcated optical axes reaches the eyepiece lens and the other reaches the distance measurement component 11.

20 The distance measurement component 11 detects an oblique distance to a measurement point (which is sighted) by using a phase modulation measurement method, a pulse radar method, or the like, while an angle measurement/control component 12 detects a vertical angle
25 θ_p and a horizontal angle θ_h . Further, the sighting

telescope 17 can be rotated about each of the horizontal and vertical axes Lh and Lp by using an actuator (not shown), such as a stepping motor. This motor driven rotation of the sighting telescope 17 is controlled by the angle measurement/control component 12.

The distance measurement component 11 and the angle measurement/control component 12 are connected to a system control circuit 13, whereby they are controlled by signals from the system control circuit 13. For example, the distance measurement component 11 detects a distance in accordance with signals from the system control circuit 13, and outputs the detected data or measurement data to the system control circuit 13. On the other hand, the angle measurement/control component 12 continuously detects angles at a regular timing and outputs the detected data or measurement data to the system control circuit 13 when it is required. Further, the angle measurement/control component 12 controls the rotational movement of the sighting telescope 17 about the horizontal and vertical axes Lh and Lp by driving the stepping motor. The detected data, such as an oblique distance, horizontal angle, and vertical angle, are processed in the system control circuit 13. The system control circuit 13 is also connected to a switch group 14, a display 15 (ex. LCD), an interface circuit 16, and

so on.

A computer 40, such as a notebook sized personal computer, may be connected to the interface circuit 16 through an interface cable. Namely, the surveying instrument 10 can transmit measurement data to the computer 40 via the interface cable. Further, the surveying instrument 10 can be controlled by control signals from the computer 40. For example, a sighting operation of the sighting telescope 17, to an arbitrary direction (horizontal angle θ_h and vertical angle θ_p), may be controlled by the computer 40. Note that, the interface circuit 16 is also available for other peripheral devices, such as a data collector, and the like, which are not shown.

The computer 40 is generally comprised of a CPU 41, a recording medium 42, input devices including a mouse 43 and a keyboard 44, a display (image indicating device) 45, and an interface circuit 46. Examples of the recording medium 42 are a hard disk, DVD, MO, and IC card. Further, the display 45 includes an LCD, CRT, and so on. As described above, the interface circuit 46 is connected to the interface circuit 16 of the surveying instrument 10 via the interface. Further, the interface circuit 46 can be connected to a digital still camera 20. Namely, an image captured by the digital still camera 20 is

transmitted to the computer 40 as digital image data and stored in the recording medium 42 via the interface circuit 46, for example.

With reference to Fig. 1, Fig. 2, and Fig. 3, a single photograph orientation process in the surveying system of the present embodiment will be described. Fig. 2 is a flowchart of the single photograph orientation process in the surveying system of the present embodiment. Fig. 3 schematically illustrates an arrangement of the surveying instrument and the camera in the surveying system of the present embodiment.

In Step 101, an operator takes a picture or image around the surveying area with the digital still camera (DSC) 20. Further, the obtained digital image data are transmitted to the computer 40 via the interface cable, and then stored in the recording medium 42. Note that, a plurality of measurement points, which are to be measured, is included within the above captured digital image (referred to as a schematic image) taken by the digital still camera 20.

In Step 102, the schematic image is indicated on the display 45 of the computer 40, for example. At this time a plurality of points (or pixels) on the schematic image are selected by the operator by using a pointing device such as a mouse 43. Thereby, substantial points

in the substantial or object space, which correspond to the selected pixels, are designated as control points P_i ($i=1, 2, \dots, n$), where a control point is a measurement point that is arbitrarily selected for calculating the orientation of a schematic image. Further, the positions of image points P_i' that correspond to each of the control points P_i are derived as two-dimensional image coordinates $(x_{p_i'}, y_{p_i'})$. Note that, the image coordinate system is a two-dimensional coordinate system of which the origin is at the upper left corner of the image with the y' -axis being positive in the downward direction. Further, the number "n" of control points which are three dimensionally arranged, may be more than 11.

In Step S103, an oblique distance and the angles (such as vertical and horizontal angle) of each control point P_i , which are appointed in Step S102, are measured by an operator by using the survey instrument 10. Measured values are then fed to the interface circuit 46 of the computer 40 via the interface circuit 16. At the CPU 41, three-dimensional coordinates $(X_{p_i}, Y_{p_i}, Z_{p_i})$ for each of the control points P_i are calculated in a predetermined surveying coordinate system. At this time, the correspondence between the surveying coordinates $(X_{p_i}, Y_{p_i}, Z_{p_i})$ for each of the control points P_i and the image coordinates $(x_{p_i'}, y_{p_i'})$ for image points P_i' is

determined. Note that, the origin of the surveying coordinate system may be taken at the sighting origin O_s of the surveying instrument 10, and the absolute coordinates, including latitude and longitude or any type of positioning format defined by the relevant surveying authority, may be adapted to the above survey coordinates. Further, the surveying coordinates calculation may be carried out in the surveying instrument 10, and later the calculated data may be sent to the computer 40.

As will be explained in detail later, exterior orientation parameters for the digital still camera 20, which represent the position and the inclination of the camera 20 at the moment when the schematic image was taken, are calculated in Step S104, in accordance with the correspondence between the surveying coordinates and the image coordinates for each of the control points P_i , by means of space resection. Further, inner orientation parameters for compensating for aberrations from the collinear condition due to lens distortion or displacement of the principal point from the image center, may be calculated. Namely, the position or the surveying coordinates (X_o, Y_o, Z_o) of the origin O_c of the three-dimensional camera coordinate system, which is fixed in the digital still camera 20, and the rotational

angle (ω, ϕ, κ) about the x-axis, y-axis, and z-axis of the camera coordinate system, at the time, are derived as exterior orientation parameters. Further, the inner orientation parameters (f : distance from the center of projection for the lens or the principal distance; D_2, D_4, D_6 : second, fourth, and sixth order components of the distortion; N_1, N_2 : unsymmetrical components of distortion; X_c, Y_c : displacement of the principal point from the center of the image) are obtained. Thereby, the perspective projection relationship between the image coordinates and the surveying coordinates is established. Note that, when the inner orientation parameters are definite for the above ($f, D_2, D_4, D_6, N_1, N_2, X_c, Y_c$), the number of control points required for calculating the exterior and inner orientation parameters is at least seven. Among these control points, at least three are required to calculate the exterior orientation parameters ($X_0, Y_0, Z_0, \omega, \phi, \kappa$). Note that, in the present embodiment, eleven (or more) control points are required to calculate the exterior and inner orientations.

Note that, the camera coordinate system is a left-handed coordinate system of which the origin O_c is located at the center of the lens or the center of the projection, and in which the y-axis and z-axis are parallel to each of the s' -axis and t' -axis of the screen

coordinate system. Further, the x-axis of the camera coordinate system is normal to the imaging surface and is oriented to the side opposite to the imaging surface from the center of the projection. Namely, any point on the
5 imaging surface is represented by the camera coordinates $(-f, y, z)$. Here, the screen coordinate system is a two-dimensional coordinate system of which the origin is defined at the principal point with each of the s'-axis and t'-axis arranged in parallel with each of the x'-axis and y'-axis, that is, in parallel with each of the
10 horizontal and vertical lines of the imaging device 21 (see Fig. 4).

As described above, the single photograph orientation process of the present embodiment ends. Note
15 that, the image capturing operation in Step S101 can be excluded and an image taken previously may be used as a schematic image, in place. Further, although the single photograph orientation process in the present embodiment is described with reference to the flowchart of Fig. 2,
20 Step S103 may be carried out prior to Steps S101 and S102. Furthermore, previously measured or given measurement data, including the data for the triangulation control point, any type of map data, or geographical data, may be used as measurement information
25 for control points.

With reference to Fig. 4 and Fig. 5, a principle for obtaining the exterior orientation parameters (position and the inclination) and the inner orientation parameters of the digital still camera 20, by space resection (Step S104), will be explained.

Fig. 4 schematically illustrates the relations between the three control points P_1 , P_2 , and P_3 , and the corresponding image points P_1' , P_2' , and P_3' on the imaging surface S . Fig. 5 is a flowchart of the space resection program that calculates exterior orientation parameters $(X_0, Y_0, Z_0, \omega, \phi, \kappa)$, which represent the position and the inclination of the digital still camera 20, and inner orientation parameters $(f, D_2, D_4, D_6, N_1, N_2, X_C, X_C)$ which depend on the optical system of the camera 20. For the space resection calculation, a least square method including a successive approximation solution is applied. Note that, although it is acceptable for the number of control points to be seven or more, here, a case when eleven points are designated for the control points, is explained, as an example. However, for convenience, only three control points P_1 , P_2 , and P_3 are illustrated in Fig. 4.

In Step 201, appropriate initial values $(X_{G0}, Y_{G0}, Z_{G0}, \omega_G, \phi_G, \kappa_G)$ and $(f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG})$ are given as approximate values for the exterior orientation

parameters $(X_0, Y_0, Z_0, \omega, \phi, \kappa)$, representing the position and the inclination of the camera, and the inner orientation parameters $(f, D_2, D_4, D_6, N_1, N_2, X_C, Y_C)$. Then in Step S202, approximate image coordinates (xp_{G1}', yp_{G1}') of the image point P_1' ($i=1, 2, \dots, 11$), which correspond to each of the eleven control points P_i , are calculated from the surveying coordinates (Xp_i, Yp_i, Zp_i) of the respective control points P_i , by using the given exterior orientation parameters $(X_{G0}, Y_{G0}, Z_{G0}, \omega_G, \phi_G, \kappa_G)$ and inner orientation parameters $(f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG})$.

Namely, the coordinates (xp_i, yp_i, zp_i) of the control points P_i ($i=1, 2, 3$) in the camera coordinate system are derived from coordinates (Xp_i, Yp_i, Zp_i) of the surveying coordinate system by Eq. (1), thereby, approximate camera coordinates $(xp_{G1}, yp_{G1}, zp_{G1})$ of the control points P_i are obtained by substituting the approximate exterior orientation parameters $(X_{G0}, Y_{G0}, Z_{G0}, \omega_G, \phi_G, \kappa_G)$ and the surveying coordinates (xp_i, yp_i, zp_i) of the control points P_i into Eq. (1).

$$\begin{pmatrix} xp_i \\ yp_i \\ zp_i \end{pmatrix} = \begin{pmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{pmatrix} \begin{pmatrix} Xp_i - X_0 \\ Yp_i - Y_0 \\ Zp_i - Z_0 \end{pmatrix} \quad (1)$$

where $\{T_{jk}\}$ represents a rotational matrix, and each of the elements T_{jk} are described in the following forms.

$$T_{11} = \cos \phi \cdot \cos \kappa$$

$$T_{12} = \cos \omega \cdot \sin \kappa + \sin \omega \cdot \sin \phi \cdot \cos \kappa$$

$$T_{13} = \sin \omega \cdot \sin \kappa - \cos \omega \cdot \sin \phi \cdot \cos \kappa$$

$$T_{21} = -\cos \phi \cdot \sin \kappa$$

$$T_{22} = \cos \omega \cdot \cos \kappa - \sin \omega \cdot \sin \phi \cdot \sin \kappa$$

$$5 \quad T_{23} = \sin \omega \cdot \cos \kappa + \cos \omega \cdot \sin \phi \cdot \sin \kappa$$

$$T_{31} = \sin \phi$$

$$T_{32} = -\sin \omega \cdot \cos \phi$$

$$T_{33} = \cos \omega \cdot \cos \phi$$

The screen coordinates (sp_i', tp_i') of the image point P_i' corresponding to the control points P_i , which have not being yet been compensated by the inner orientation parameters, are derived from the collinear condition (wherein a control point, the center of projection, and the corresponding image point are aligned on the same line). Therefore, the uncompensated screen coordinates (sp_i', tp_i') are calculated by substituting the exterior orientation parameters ($X_0, Y_0, Z_0, \omega, \phi, \kappa$) and the camera coordinates ($x_{p_i}, y_{p_i}, z_{p_i}$) of control points P_i into the following Eq. (2).

$$20 \quad \begin{aligned} sp_i' &= -f \frac{yp_i}{xp_i} = -f \frac{T_{21}(X_{p_i} - X_0) + T_{22}(Y_{p_i} - Y_0) + T_{23}(Z_{p_i} - Z_0)}{T_{11}(X_{p_i} - X_0) + T_{12}(Y_{p_i} - Y_0) + T_{13}(Z_{p_i} - Z_0)} \\ tp_i' &= -f \frac{zp_i}{xp_i} = -f \frac{T_{31}(X_{p_i} - X_0) + T_{32}(Y_{p_i} - Y_0) + T_{33}(Z_{p_i} - Z_0)}{T_{11}(X_{p_i} - X_0) + T_{12}(Y_{p_i} - Y_0) + T_{13}(Z_{p_i} - Z_0)} \quad (2) \end{aligned}$$

Although, the uncompensated screen coordinates (sp_i', tp_i') are affected by distortion, the effect is

compensated for by substituting the screen coordinates
 (sp_i', tp_i') of each image point P_i' and the approximate
 inner orientation parameters $(f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG})$
 into the following Eq. (3). Namely, compensated
 5 approximate screen coordinates (scp_{G1}', tcp_{G1}') are
 obtained.

$$R^2 = sp_i'^2 + tp_i'^2$$

$$scp_i' = sp_i'(1 + D_2 R^2 + D_4 R^4 + D_6 R^6) + (R^2 + 2sp_i'^2)N_1 + 2sp_i' tp_i' N_2 + X_C \quad (3)$$

$$tcp_i' = tp_i'(1 + D_2 R^2 + D_4 R^4 + D_6 R^6) + 2sp_i' tp_i' N_1 + (R^2 + 2tp_i'^2)N_2 + Y_C$$

10 Further, approximate image coordinates (xp_{G1}', yp_{G1}')
 of the image points P_i' can be derived by substituting
 the compensated approximate screen coordinates
 (scp_{G1}', tcp_{G1}') into the following Eq. (4).

$$xp_i' = scp_i' / (-Px) + W/2$$

$$15 \quad yp_i' = tcp_i' / Py + H/2 \quad (4)$$

where Px and Py are the pixel pitches of the CCD or the
 image in the horizontal and vertical directions
 respectively, and W and H are the numbers of pixels in the
 CCD or the image, which are aligned in the horizontal and
 20 vertical directions, respectively.

In Step S203, a merit function Φ is calculated in
 order to determine whether the approximately given
 exterior orientation parameters $(X_{G0}, Y_{G0}, Z_{G0}, \omega_G, \phi_G, \kappa_G)$ and
 inner orientation parameters $(f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG})$
 25 are appropriate. For example, the merit function Φ is

determined by the following Eq. (5).

$$\Phi = \sum_{i=1}^{11} \left\{ (xp_i' - xp_{Gi}')^2 + (yp_i' - yp_{Gi}')^2 \right\} \quad (5)$$

Namely, in the present embodiment, the merit function Φ corresponds to the total amount of squared distances between the image coordinates (xp_i', yp_i') of image points P_i' corresponding to the control points P_i (which are selected in the schematic image), and the approximate image coordinates (xp_{Gi}', yp_{Gi}') of the image points P_i' calculated from the surveying coordinates (Xp_i, Yp_i, Zp_i) of the control points P_i , the approximately given exterior orientation parameters $(X_{G0}, Y_{G0}, Z_{G0}, \omega_G, \phi_G, \kappa_G)$ and inner orientation parameters $(f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG})$.

Then, whether the merit function is smaller than a predetermined value is determined, in Step S204. That is, whether the approximate image coordinates (xp_{Gi}', yp_{Gi}') of the image points P_i' , which are obtained from the approximately given exterior orientation parameters $(X_{G0}, Y_{G0}, Z_{G0}, \omega_G, \phi_G, \kappa_G)$ and inner orientation parameters $(f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG})$, are sufficiently close to the image coordinates (xp_i', yp_i') of the image points P_i' corresponding to the control points P_i , which are designated on the schematic image, is determined. When the value Φ is smaller than the predetermined

value, this process is terminated and the values of the presently given exterior orientation parameters ($X_{G0}, Y_{G0}, Z_{G0}, \omega_G, \phi_G, \kappa_G$) and inner orientation parameters ($f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}$) are determined as the exterior and inner orientation parameters that represent the exterior orientation parameters (which indicate position and the inclination of the camera) and inner orientation parameters when the schematic image was captured.

On the other hand, when the value of Φ is determined to be larger or equal to the predetermined value, in Step S204, then in step S205, compensation values ($\delta X, \delta Y, \delta Z, \delta \omega, \delta \phi, \delta \kappa, \delta f, \delta D_2, \delta D_4, \delta D_6, \delta N_1, \delta N_2, \delta X_C, \delta Y_C$) for the approximately given exterior orientation parameters ($X_{G0}, Y_{G0}, Z_{G0}, \omega_G, \phi_G, \kappa_G$) and inner orientation parameters ($f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}$) are calculated by using the least squares method, for example. Namely, (scp_1', tcp_1') of Eq. (3) are substituted for (sp_1', tp_1') of Eq. (2), which represents the collinearity condition. Eq. (2) is then subjected to Taylor's expansion at the approximate exterior orientation parameters ($X_{G0}, Y_{G0}, Z_{G0}, \omega_G, \phi_G, \kappa_G$) and inner orientation parameters ($f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}$) and the higher order terms are neglected so as to linearize the formula. Accordingly, the normal equations, for which the compensation values

($\delta X, \delta Y, \delta Z, \delta \omega, \delta \phi, \delta \kappa$) and ($\delta f, \delta D_2, \delta D_4, \delta D_6, \delta N_1, \delta N_2, \delta X_c, \delta Y_c$) are regarded as unknown values, are derived in order to obtain the appropriate compensation values ($\delta X, \delta Y, \delta Z, \delta \omega, \delta \phi, \delta \kappa$) and ($\delta f, \delta D_2, \delta D_4, \delta D_6, \delta N_1, \delta N_2, \delta X_c, \delta Y_c$).

5 In Step S206, the approximate exterior orientation parameters ($X_{G0}, Y_{G0}, Z_{G0}, \omega_G, \phi_G, \kappa_G$) and inner orientation parameters ($f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{cG}, Y_{cG}$) are altered by the compensation values ($\delta X, \delta Y, \delta Z, \delta \omega, \delta \phi, \delta \kappa$) and ($\delta f, \delta D_2, \delta D_4, \delta D_6, \delta N_1, \delta N_2, \delta X_c, \delta Y_c$) which are obtained in Step
10 S205. That is, each of the values ($X_{G0}, Y_{G0}, Z_{G0}, \omega_G, \phi_G, \kappa_G$) and ($f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{cG}, Y_{cG}$) is replaced by the values ($X_{G0} + \delta X, Y_{G0} + \delta Y, Z_{G0} + \delta Z, \omega_G + \delta \omega, \phi_G + \delta \phi, \kappa_G + \delta \kappa$) and ($f_G + \delta f, D_{2G} + \delta D_2, D_{4G} + \delta D_4, D_{6G} + \delta D_6, N_{1G} + \delta N_1, N_{2G} + \delta N_2, X_{cG} + \delta X_c, Y_{cG} + \delta Y_c$) to thereby renew or compensate the position, inclination,
15 and inner orientation parameters of the camera. Then the process returns to Step S202, so that Steps S202 through S206 are repeated until the value Φ is determined to be smaller than the predetermined value in Step S204.

20 With reference to Fig. 1, Fig. 6, and Fig. 7, the automatic surveying operation using the surveying system of the present embodiment will be explained.

Fig. 6 schematically illustrates an example of the schematic image indicated on the display 45. An operator operates the mouse 43 and controls a mouse
25 cursor on the schematic image in order to define an area

(a surveying area) "A" that is to be surveyed. The computer 40 obtains a collinear line LN_c that satisfies the collinear condition of an arbitrary pixel within the surveying area "A" (e.g. the image point Q_6' corresponding to an object point Q_6), as shown in Fig. 7. The surveying instrument 10 scans along the collinear line LN_c (which is carried out by moving the collimation axis LN_0 of the surveying instrument along the collinear line LN_c under the condition that the collimation axis LN_0 intersects the collinear line LN_c) and obtains measurement data at a predetermined interval (e.g. points R_1-R_5) in accordance with signals from the computer 40, so that the object point Q_6 is searched with reference to the measurement coordinate values obtained when sighting the surveying instrument 10 to each of the points R_j ($j=1,2,\dots,6$). This operation may be carried out for all pixels within the surveying area "A". Further, the surveying area "A" may be automatically divided into arbitrarily distanced grids (e.g. regular intervals) and the scanning operation may be carried out only for each of the nodal points on the grids. Further, a curvature line "B" (or a segment) can also be defined and they may be automatically divided into arbitrary intervals (e.g. regular intervals). In the present embodiment, both a surveying area "A" and a curvature line "B" are

determined by an operator. An area or a line may also be divided with respect to regular angular intervals for a surveying instrument. Further, a surveying area "A" and a curvature line "B" can be defined automatically by an
5 image processing executed on the schematic image. For example, an area and line may be detected with respect to an arbitrary color or luminance, or by using an edge enhancing process.

When the surveying instrument 10 is sighted to the point R_2 on the collinear line LN_C , a position which is measured is the object point Q_2 which is outside the surveying area "A". The image coordinates (x_{q2}', y_{q2}') on the schematic image, which corresponds to the object point Q_2 , is calculated by substituting the exterior
15 orientation parameters $(X_0, Y_0, Z_0, \omega, \phi, \kappa)$ and the inner orientation parameters $(f, D_2, D_4, D_6, N_1, N_2, X_C, X_C)$ of which the values are obtained by the single photograph orientation process, and the surveying coordinates (X_{q2}, Y_{q2}, Z_{q2}) of the object point Q_2 , into Eq. (1) through
20 Eq. (4). However, the image coordinates (x_{q2}', y_{q2}') which correspond to the measured object point Q_2 are different from the image coordinates (x_{q6}', y_{q6}') of the designated image point Q_6' since the object point Q_2 is not equal to the object point Q_6 which corresponds to the designated
25 image point Q_6' .

On the other hand, the point R_6 on the collinear line LN_c coincides with the object point Q_6 where the collinear line LN_c intersects with a subject within the surveying area "A". Namely, image coordinates calculated from surveying coordinates that are obtained when the surveying instrument 10 is sighted to the point R_6 , coincide with the image coordinates $(x_{q6'}, y_{q6'})$ of the designated image point Q_6' . Consequently, automatic measurement for an object point that corresponds to an arbitrarily designated pixel on the schematic image can be achieved by carrying out surveying along a collinear line corresponding to the arbitrarily designated pixel (a pixel within the surveying area "A" in the present embodiment), and searching for an object point of which the image coordinates obtained from its surveying coordinates substantially coincide with the image coordinates of the arbitrarily designated pixel.

With reference to Fig. 8 to Fig. 11, the automatic surveying operation of the present embodiment will be explained in detail.

Fig. 8 is a flowchart of the automatic surveying operation program. The program is executed in the CPU 41. The automatic surveying operation of Fig. 8 is carried out after the completion of the single photograph orientation process for the schematic image. Therefore,

the exterior and inner orientation parameters for the digital still camera 20, when the schematic image was taken, have already been obtained. In Step S301, the surveying area "A", which is defined by an operator on the schematic image on the monitor 45 by using the mouse 43, is received. Further, all pixels within the surveying area "A" are numbered (1 to N, where "N" is the total number of pixels inside the surveying area "A").

In Step S302, "i" is set for a pixel number "i", so that Step S303 through Step S306 are repeated until "i" reaches "N". In Step S303, surveying along the collinear line that corresponds to the image coordinates (x_i', y_i') of a pixel number "i" is automatically carried out. Namely, the position of an object point that corresponds to the pixel with the pixel number "i" is searched and measured by comparison between the image coordinates corresponding to measured surveying coordinates and the image coordinates (x_i', y_i') of the pixel with the pixel number "i" (object point searching process). Note that, the detail of the object point searching process will be explained latter.

In Step S304, the measurement data of the image coordinates (x_i', y_i') obtained by the object point searching process of Step S303 is recorded in the recording medium 42. In Step S305, whether the pixel

number "i" is larger than the total pixel number "N" is determined. Namely, whether the object point searching process has been carried out for all pixels inside the surveying area "A" is determined. When it is determined
5 that it has not, i.e. $i \neq N$, the number "i" is incremented by one in Step S306 and the process returns to Step S303. On the other hand, when it is determined that $i = N$, this automatic surveying operation ends.

Fig. 9 is a flowchart of the object point
10 searching process that is executed in Step S303. In Step S401, a unit collinear vector (r_{ix}, r_{iy}, r_{iz}) for the collinear line LN_c of the image coordinates (x_i', y_i') is calculated (unit collinear vector calculating process). In the object point searching process, the surveying is
15 carried out by sighting the surveying instrument 10 to hypothetical sighting points R_j which are arranged on the collinear line LN_c at predetermined intervals. In Step S402, the distance "L" from the origin $O_c (X_o, Y_o, Z_o)$ of the camera coordinate system to a hypothetical sighting
20 points R_j on the collinear line LN_c is set to the initial distance L_a .

In Step S403, the surveying coordinates (X_{Rj}, Y_{Rj}, Z_{Rj}) of the hypothetical sighting points R_j are calculated from the unit collinear vector (r_{ix}, r_{iy}, r_{iz}) ,
25 which is obtained in Step S401, and the distance "L", as

follows.

$$X_{Rj} = X_o + r_{1x} \times L$$

$$Y_{Rj} = Y_o + r_{1y} \times L \quad (6)$$

$$Z_{Rj} = Z_o + r_{1z} \times L$$

5 Further, the horizontal angle θh and the altitude θp for sighting the sighting telescope 17 to the hypothetical sighting point R_j are obtained by Eq. (7) and Eq. (8).

$$\theta h = \begin{cases} \sin^{-1} \left(\frac{\frac{Y_{Ri}}{\sqrt{X_{Ri}^2 + Y_{Ri}^2 + Z_{Ri}^2}}}{\cos(\sin^{-1} \frac{Z_{Ri}}{\sqrt{X_{Ri}^2 + Y_{Ri}^2 + Z_{Ri}^2}})} \right) & (X_{Ri} \geq 0) \\ \pi - \sin^{-1} \left(\frac{\frac{Y_{Ri}}{\sqrt{X_{Ri}^2 + Y_{Ri}^2 + Z_{Ri}^2}}}{\cos(\sin^{-1} \frac{Z_{Ri}}{\sqrt{X_{Ri}^2 + Y_{Ri}^2 + Z_{Ri}^2}})} \right) & (X_{Ri} < 0) \end{cases} \quad (7)$$

$$10 \quad \theta p = \sin^{-1} \left(\frac{Z_{Ri}}{\sqrt{X_{Ri}^2 + Y_{Ri}^2 + Z_{Ri}^2}} \right) \quad (8)$$

Note that, as described in Fig. 10, the origin of the surveying coordinates system is positioned at the sighting origin OS in Eq. (7) and Eq. (8). When $\theta p = \theta h$, the X-axis coincides with the horizontal axis Lh, the Y-axis coincides with the vertical axis Lp, and the Z-axis coincides with the collimation axis (optical axis) LN_o.
15 Further, at this time, the surveying instrument 10

orients the collimation axis (optical axis) LN_0 of the sighting telescope 17 to (θ_h, θ_p) in accordance with signals from the computer 40.

In Step S404, the measurement or surveying is carried out for the direction which is sighted in Step S403. According to the above measurement, the surveying coordinates $(X_{Q_i}, Y_{Q_i}, Z_{Q_i})$ for the object point Q_i is calculated from the substantial measurement data for the object point Q_i which corresponds to the hypothetical sighting point R_i . The image coordinates (x_{Q_i}', y_{Q_i}') which correspond to the surveying coordinates $(X_{Q_i}, Y_{Q_i}, Z_{Q_i})$ of the object point Q_i are then calculated from the exterior orientation parameters $(X_0, Y_0, Z_0, \omega, \phi, \kappa)$ and the inner orientation parameters $(f, D_2, D_4, D_6, N_1, N_2, X_C, X_C)$, in Step S405.

In Step S406, whether the image coordinates (x_{Q_i}', y_{Q_i}') of the object point Q_i coincide with the image coordinates (x_1', y_1') of the collinear line LN_c is determined. For example, when the distance between the image coordinates (x_{Q_i}', y_{Q_i}') and the image coordinates (x_1', y_1') is within a predetermined value, it is determined that the coordinates (x_{Q_i}', y_{Q_i}') of the object point Q_i coincide with the image coordinates (x_1', y_1') of the collinear line LN_c . In this situation, the surveying coordinates $(X_{Q_i}, Y_{Q_i}, Z_{Q_i})$ of the object point Q_i , which are

calculated in Step S407, are defined as the surveying coordinates of the pixel (x_i', y_i') that corresponds to the pixel number "i". Accordingly, the object point searching process for the pixel number "i" ends. On the other hand, when it is determined that the above two sets of coordinates do not coincide, the distance "L" is replaced by "L+ ΔL " in Step S408, and the processes from Step S403 are repeated. Note that, " ΔL " is an increment for the distance "L" and defined by regarding the required precision and the surveying time.

Next, with reference to Fig. 11, the unit collinear vector calculating process that is carried out in Step S401 is explained. Fig. 11 is a flowchart of the unit collinear vector calculating process.

In the present embodiment, a unit collinear vector is calculated by means of the least square method. Namely, in the unit collinear vector calculating process of the present embodiment, an arbitrary unit vector $(r_{Gix}, r_{Giy}, r_{Giz})$ is given as an approximate unit collinear vector for a pixel (x_i', y_i') , in the first step. Therefore in Step S501, the image coordinates (x_{Gi}', y_{Gi}') for the surveying coordinates $(X_0 + r_{Gix}, Y_0 + r_{Giy}, Z_0 + r_{Giz})$ that correspond to the end of the unit vector $(r_{Gix}, r_{Giy}, r_{Giz})$ which extends from the origin $O_c: (X_0, Y_0, Z_0)$ of the camera coordinates system, are calculated using Eq. (1) to Eq.

(4) with respect to the exterior orientation parameters $(X_0, Y_0, Z_0, \omega, \phi, \kappa)$ and the inner orientation parameters $(f, D_2, D_4, D_6, N_1, N_2, X_C, X_C)$.

In Step S502, a merit function $\Psi = (x_i' - x_{Gi}')^2 + (y_i' - y_{Gi}')^2$ is calculated for the image coordinates (x_{Gi}', y_{Gi}') obtained in Step S501. Whether the merit function Ψ is smaller than a predetermined value is determined in Step S503. When it is determined that the merit function Ψ is smaller than the predetermined value, the unit vector $(r_{Gix}, r_{GiY}, r_{Giz})$ is defined as the unit collinear vector (r_{ix}, r_{iy}, r_{iz}) of the pixel that corresponds to the pixel number "i", in Step S504, so that this unit collinear vector calculating process for the pixel number "i" ends.

On the other hand, when it is determined in Step S503 that the merit function Ψ is not smaller than the predetermined value, compensation values $(\delta r_{ix}, \delta r_{iy}, \delta r_{iz})$ for the approximate unit vector $(r_{Gix}, r_{GiY}, r_{Giz})$ are calculated by means of the least square method, in Step S505. Further, the approximate unit vector is replaced by a new unit vector $(r_{Gix} + \delta r_{ix}, r_{GiY} + \delta r_{iy}, r_{Giz} + \delta r_{iz})$. The process then returns to Step S501, so that Step S501 to Step S505 are repeated until the merit function Ψ is determined to be smaller than the predetermined value, in Step S503.

Note that, the volume of the surveying area is

calculated from the measurement data of the surveying area, which is obtained from the above automatic surveying operation. Further, the area, the circumferential length, or the like, which relates to the surveying area can also be calculated by surveying only the circumference of the designated surveying area.

As described above, according to the present embodiment, a measurement point which is designated on a schematic image can be automatically sighted by a surveying instrument, so that the measurement point can be automatically measured. Further, although it is not depicted, when using a surveying instrument with a CCD provided inside, the sighting telescope can be more precisely sighted to a point by designating the point on an image captured by the CCD, which has a higher magnification than the schematic image, after rough sighting to the point. Further, according to the present embodiment, the surveying operation within a surveying area can be automatically carried out when an operator merely defines the surveying area on the schematic image, so that efficiency of the surveying operation can be greatly improved.

Note that, when using a lens system having a long focal length, such as a telephoto lens, distortion which is a part of the inner orientation parameters is

sufficiently small, so that on some occasions it can be neglected. Namely, the inner orientation parameters $(D_2, D_4, D_6, N_1, N_2)$ can be neglected, so that the remaining inner orientation parameters are reduced to (f, X_c, Y_c) .

5 In this case, only five control points P_i which are three-dimensionally arranged are required for obtaining the inner orientation parameters (f, X_c, Y_c) . Further, when the displacement of the principal point from the image center, the unsymmetrical components of the
10 distortion, and the fourth and sixth distortion components are negligible, the remaining inner orientation parameters are reduced to (f, D_2) , so that the number of control points required for obtaining the inner parameters is reduced to four. As described above, since
15 the number of unknown inner orientation parameters is reduced, the number of control points is also reduced, so that labor and time for the surveying can be reduced.

In the present embodiment, the digital still camera 20 is arbitrarily disposed with respect to the
20 surveying instrument 10, however, the digital still camera 20 may be disposed at the position which is optically equivalent to the sighting telescope 17 of the surveying instrument 10, by using a camera mounting accessory equipped on the surveying instrument 10. In
25 this case, the number of unknown exterior orientation

parameters can be reduced, so that the number of control points can be reduced. Further, when a schematic image is captured with the digital still camera 20 placed at the position which is optically equivalent to the sighting telescope 17 of the surveying instrument 10 (when the center of projection for an imaging optical system of an imaging device is placed at a position that is optically equivalent to the sighting origin of a sighting telescope), the horizontal angle and the vertical angle can be directly calculated from image coordinates, so that the process is facilitated.

In the following, an alternate embodiment when the digital still camera 20 is positioned at a point where it is optically equivalent to the sighting telescope 17 is explained with reference to Fig. 12. In this case, X_0 , Y_0 , and Z_0 are all equal to zero ($X_0=Y_0=Z_0=0$) for the exterior orientation parameters ($X_0, Y_0, Z_0, \omega, \phi, \kappa$). When the y-axis and the Z-axis of the camera coordinate system are defined as to correspond to the horizontal axis L_h and the vertical L_p of the surveying instrument, respectively, the surveying coordinate system and the camera coordinate system can be regarded as having the same coordinate system. Therefore, when the surveying instrument 10 is sighted onto a measurement point P_n on the schematic image (see

Fig. 6), the image coordinates (x_{pn}', y_{pn}') of the image point P_n' for the measurement point P_n can be directly obtained from the horizontal angle θ_{h_n} and the vertical angle θ_{p_n} of the surveying instrument 10 sighted onto the measurement point P_n , and principal distance f of the imaging lens by substituting them into the following equations:

$$\begin{aligned} x_{pn}' &= f \cdot \tan(\theta_{h_n} - \theta_{h_0}) / Px + W/2, \\ y_{pn}' &= f \cdot \tan(\theta_{p_n} - \theta_{p_0}) / Py + W/2 \end{aligned} \quad (9)$$

where θ_{h_0} and θ_{p_0} are initial sighting directions when the schematic image is captured (note that, when distortion compensation is necessary, the inner orientation parameters are also used). Therefore, when a sighting position (x_{pn}', y_{pn}') is designated on the schematic image, the horizontal angle θ_{h_n} and the altitude θ_{p_n} of the measurement point P_n can be calculated as the inverse of Eq. (9) that is:

$$\begin{aligned} \theta_{h_n} &= \tan^{-1}(Px(x_{pn}' - W/2)/f) + \theta_{h_0} \\ \theta_{p_n} &= \tan^{-1}(Py(y_{pn}' - H/2)/f) + \theta_{p_0}. \end{aligned} \quad (10)$$

Therefore, the surveying instrument can be sighted in the direction represented by Eq. (10).

Fig. 12 is a flowchart of the surveying operation for the present alternate embodiment.

In Step S601, correspondence between the schematic image and the surveying coordinates is

establish based on the single photograph orientation process described in Fig. 2. In Step S602, a measurement point P_n is designated on the schematic image as a sighting point by using the mouse 43 (see Fig. 6).
 5 Further, a sighting mark is indicated on the designated point to indicate the sighting position. In Step S603, the sighting angels (θ_{h_n} , θ_{p_n}) are calculated by substituting the position P_n' ($x_{p_n'}$, $y_{p_n'}$) on the schematic image for the designated sighting point (measurement
 10 point P_n) into Eq. (10). Further, the surveying instrument is oriented in the above direction. In Step S604, the indication (color, shape, or size) of the sighting point that has already been sighted is changed and displayed on the schematic image. By this, this
 15 surveying operation ends.

According to the present alternate embodiment, an operator can visually recognize whether the sighting is finished on the schematic image, so that the efficiency of the sighting is improved.

20 Further, another alternate embodiment is described, wherein a surveying operation is carried out for a sighting point which has three-dimensional position information, such as when a measurement point to be sighted is given three-dimensional positional information
 25 as planning values, such as a staking point, or when

sighting a measurement point has already been measured in a previous surveying. When three-dimensional information of a measurement point P_n is given, the surveying instrument 10 can be automatically sighted by calculating the horizontal angle θ_{h_n} and vertical angle θ_{p_n} by substituting the coordinates (X_n, Y_n, Z_n) of the measurement point P_n into R_i (X_{Ri}, Y_{Ri}, Z_{Ri}) of Eq. (7) and Eq. (8). Fig. 13 shows a flowchart of the surveying operation in this case.

In Step S701, correspondence between the schematic image and the surveying coordinates is established according to the single photograph orientation process described in Fig. 2. In Step S702, a measurement point (e.g. staking point) of which the three-dimensional coordinates are known is indicated on the schematic image. An operator defines a sighting direction by designating a measurement point on the schematic image, the point which is to be sighted, by using a pointing device, such as the mouse 43, in Step S703. In Step S704, the three-dimensional coordinates of the measurement point P_n are substituted into Eq. (7) and Eq. (8), in order to calculate the sighting angles $(\theta_{h_n}, \theta_{p_n})$ and to sight the surveying instrument in the direction represented by the above sighting angles. In Step S705, the indication (color, shape, or size) of the measurement

point which has already been sighted is altered. By this, this surveying operation ends.

According to the above alternate embodiment, a similar effect as that in the previous alternate embodiment can be obtained. Thus, the completion of the sighting can be visually confirmed on the schematic image and efficiency of the surveying operation is improved. Note that, in Step S703, a mark indicating a selected measurement point may be altered when the measurement point is designated. In the case of surveying a staking point and when the planning coordinate system for the staking point is not equivalent to the surveying coordinate system, the coordinate values of the staking point in the planning coordinate system are transformed to the surveying coordinate system. On the other hand, the inverse transformation can also be carried out.

In the present embodiments, the surveying instrument is oriented to the sighting point R_1 on the collinear line LN_c that corresponds to an arbitrary designated pixel, and the image coordinates (x_{Q1}', y_{Q1}') on the schematic image are calculated from the surveying coordinates (X_{Q1}, Y_{Q1}, Z_{Q1}) measured in the above sighting. Further, whether the image coordinates (x_{Q1}', y_{Q1}') coincide with the image coordinates (x_1', y_1') of the arbitrarily designated pixel is determined. However,

this may be determined by whether the surveying coordinates (X_{Q1}, Y_{Q1}, Z_{Q1}) coincide with the surveying coordinates (X_{R1}, Y_{R1}, Z_{R1}) of the sighting point R_1 .

Note that, although in the present embodiments, 5 the control points are arbitrarily designated on the schematic image by using a pointing device, it is also possible to capture an image of a reference scale of which the dimensions are known, or reference marks at arbitrary positions within the schematic image, and to calculate the 10 exterior orientation parameters by regarding them as the control points. In this case, the points on the reference scale or the reference marks may be designated on the schematic image by a pointing device or the like. Further, when the reference scale or the reference marks 15 are applied the control points on the schematic image may be automatically detected by means of image processing.

In the present embodiments, a computer connected to a surveying instrument is used, however, the function of the computer may be integrated into the surveying 20 instrument or a digital still camera. Further, although in the present embodiments, a digital image is obtained by a digital still camera, any type of image capturing device, such as a digital video camera and the like, can be used as long as it can finally produce a digital image.

25 Although the embodiments of the present invention

have been described herein with reference to the accompanying drawings, obviously many modifications and changes may be made by those skilled in this art without departing from the scope of the invention.

5 The present disclosure relates to subject matter contained in Japanese Patent Application No. 2002-190599 (filed on June 28, 2002) which is expressly incorporated herein, by reference, in its entirety.